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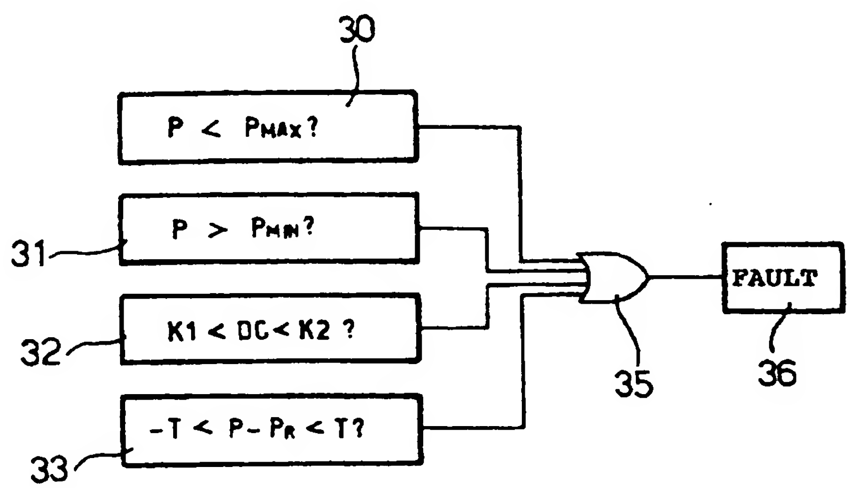

(57) Abstract

A method of diagnosing malfunctioning of a high-pressure circuit including a pump (6) for supplying fuel at a pressure value controlled by a pressure regulating solenoid valve (7) supplied with current whose duty cycle is controlled in periodic control cycles. The method consists in monitoring quantities correlated to the pressure generated by the pump (6) in successive control cycles; comparing the pattern of the quantities with reference values; and generating fault signals in the event the determined pattern fails to present a predetermined relationship with the reference values. In particular, a check is made to determine whether fuel supply pressure remains above or below maximum and minimum values; wether the duty cycle of the current supply to the solenoid valve (7) remains above or below predetermined limits; and to determine the congruency of a measured pressure value and a reference value calculated on the basis of the duty cycle.

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METHOD OF DIAGNOSING MALFUNCTIONING OF THE HIGH-PRESSURE CIRCUIT OF INTERNAL COMBUSTION ENGINE HIGH-PRESSURE INJECTION SYSTEMS

TECHNICAL FIELD

The present invention relates to a method of diagnosing malfunctioning of the high-pressure circuit of internal combustion engine high-pressure injection systems.

BACKGROUND ART

A high-pressure injection system substantially comprises a fuel tank, and a high-pressure injector supply circuit in turn comprising a pump for supplying fuel at high pressure to a manifold in turn supplying a number of injectors. The pump presents a pressure regulating solenoid valve for supplying fuel at a predetermined pressure.

In such systems, it is essential that the high-pressure circuit be monitored continually to prevent operation of the system from being impaired by a shift in the pressure sensor setting, jamming or malfunctioning of the control members or injectors, or

leakage in the circuit.

DISCLOSURE OF INVENTION

It is an object of the present invention to provide a diagnosis method capable of indicating any malfunctioning as soon as it occurs.

According to the present invention, there is provided a method of diagnosing malfunctioning of the high-pressure circuit of internal combustion engine high-pressure injection systems; said circuit including a high-pressure pump for supplying fuel at a pressure value controlled by means of control cycles; characterized in that it comprises the steps of monitoring quantities correlated to the pressure generated by said pump in successive control cycles; comparing the pattern of said quantities in said successive control cycles with reference values; and generating fault signals in the event said pattern fails to present a predetermined relationship with said reference values.

BRIEF DESCRIPTION OF DRAWINGS

A preferred non-limiting embodiment of the present invention will be described by way of example with reference to the accompanying drawings, in which:

Figure 1 shows an overall diagram of the hydraulic system of an injection system to which the diagnosis method according to the present invention is applied;

Figure 2 shows a detail of the pressure regulator of the Figure 1 system;

Figure 3 shows a block diagram of the method according to the present invention;

Figure 4 shows a maximum and minimum reference pressure graph as a function of engine speed;

Figures 5A, 5B and 5C show pressure and duty cycle graphs with an injector locked in the open position and in three different operating conditions;

Figure 6 shows the pressure/duty cycle relationship used for congruency testing.

BEST MODE FOR CARRYING OUT THE INVENTION

A general description will now be given, with reference to Figure 1, of a high-pressure injection system for internal combustion engines. The system, indicated by 1, comprises a tank 2 at atmospheric pressure, connected by a delivery line 5 to a radial-piston pump 6 presenting a pressure regulating solenoid valve (or pressure regulator) 7 connected by drain line 8 to tank 2.

Pump 6 feeds the fuel at high pressure along line 11 to a manifold 10 which provides for distributing the fuel to the injectors and damping any fluctuation in pressure caused by the action of the pump and opening of the injectors. Manifold 10 consists of a steel body preferably in the form of a parallelepipedon and in which is formed a cylindrical cavity extending along the length of the manifold and connected to line 11 by a central hole 12. Manifold 10 also presents four holes 13 spaced along the length of the manifold and connected to

four high-pressure (up to 1500 bar) supply conduits 14 of four injectors 15 of an engine 16. Each injector 15 is also connected to a conduit 17 for recirculating the fuel (for operating the injector) into tank 2.

Manifold 10 is fitted at one end with a known pressure sensor 18.

Pressure regulator 7 is conveniently formed as shown in Figure 2, and comprises a body 20 defining a conical seat 21 for a spherical shutter 22. By means of a push rod 23, shutter 22 is subjected to the combined force of a spring 24 and a solenoid 25 which cooperates with a core 26 integral with a rod 27 in turn integral with push rod 23. Shutter 22 separates an inlet conduit 28, connected to the body of pump 6, from an outlet conduit 29, connected to line 8; and varying the current supply to solenoid 25 regulates the force exerted on shutter 22 in the closing direction and, hence, the output pressure of pump 6.

Pressure is regulated by supplying solenoid 25 with a current whose duty cycle is modulated at a fixed oscillation frequency (PWM - Pulse Width Modulation - technique) and using a closed regulating loop which takes into account the actual pressure measured by pressure sensor 18, and the desired pressure value.

The method according to the present invention provides for periodically checking operation of the system 1 components, and more specifically for determining: the ability of pump 6 to generate the

required pressure; correct tightness of regulator 7; the absence of leakage in the circuit; the presence of injectors locked in the open position; correct operation of the electric circuit controlling regulator 7; and the sensitivity and correct operation of pressure sensor 18.

According to a preferred embodiment shown schematically in Figure 3, four tests are performed periodically: maximum measured pressure (block 30); minimum measured pressure (block 31); duty cycle controlling the pressure regulator (block 32); and measured pressure/duty cycle congruency (block 33).

More specifically, the maximum measured pressure test (block 30) consists in determining the pressure measured by sensor 18 in manifold 10 does not exceed a maximum permissible externally set value, e.g. 1600 bar, in a predetermined number of consecutive checks (e.g. five). A pressure in excess of the maximum permissible value (shown by line A in Figure 4) indicates the following types of fault: a shift in the setting of sensor 18 (measuring error); or regulator 7 locked in the closed position (a fault on the regulator preventing or greatly reducing pressurized fuel flow from conduit 28 to conduit 29 of regulator 7).

The minimum measured pressure test (block 31) consists in determining the measured pressure does not fall below a minimum permissible value in a predetermined number of consecutive checks, e.g. five. The minimum permissible value varies according to engine

speed, as shown by curve B in Figure 4; and a pressure below the minimum permissible value indicates the following types of fault: an injector locked in the open position; a fault on the pump (fails to ensure the required fuel flow); leakage in the circuit; or a shift in the sensor setting. The increase in the minimum permissible value alongside engine speed is important for detecting the presence of an injector locked in the open position, in that, at high engine speed, even with an injector locked in the open position, pressure may fail to fall below values which are acceptable and correspond to efficient operation at low engine speed.

Testing of the duty cycle controlling the pressure regulator (block 32) consists in determining the duty cycle (percentage measurement) does not exceed a predetermined maximum value K2 (e.g. 97%) or fall below a predetermined minimum value K1 (e.g. 2%) in a predetermined number of consecutive checks (e.g. five for the maximum and 25 for the minimum value). A duty cycle repeatedly in excess of the maximum value means the measured pressure in this period is permanently below the reference value of the system controlling the regulator, and indicates the same faults as the minimum pressure test as well as, possibly, malfunctioning of the electric circuit regulating the duty cycle. Conversely, a repeatedly low duty cycle value means the measured pressure is permanently in excess of the reference value of the system controlling the regulator,

and indicates a shift in the setting of sensor 18 or overtightness of regulator 7.

Three examples of faults caused by locking of an injector in the open position are shown in Figures 5A, 5B and 5C which show the pressure curve (dotted line) and duty cycle curve (continuous line) in three different conditions following locking of the injector at cycle 2 of the engine. More specifically, Figure 5A relates to a high-pressure condition, in which case, the fault is detected on the basis of the duty cycle remaining repeatedly in excess of the predetermined limit; Figure 5B relates to a medium-pressure condition, in which case, the fault is again detected on the basis of the excessively high duty cycle value, though more slowly than in Figure 5A; and Figure 5C relates to a low-pressure condition, in which case, the fault is detected by detecting too low a pressure value a given number of times.

The measured pressure/duty cycle congruency test (block 33) exploits the relationship between the duty cycle (or more specifically the effective current supplied to regulator 7) and the pressure measured in manifold 10, which relationship is as shown by curve C in Figure 6 which shows reference pressure PR as a function of effective current. Since curve C varies within certain limits according to the regulator used, reference value PR is assigned an upper and lower tolerance value T (e.g. 300 bar) to give two curves D1,

D2 defining a given acceptance range.

The congruency test consists in determining the duty cycle value of the current supply to solenoid valve 7 according to conveniently proportional-integral algorithms and as a function of actual measured pressure and required pressure (the latter calculated as provided for, e.g. on the basis of engine parameters as described in a further patent application filed by the present Applicant). By means of a map, the reference value PR corresponding to the determined duty cycle (in curve C) is determined; and a check is made to determine whether the value of the pressure measured by sensor 18 corresponds to reference value PR within the given tolerance (i.e. whether the measured pressure value falls within the given tolerance range). A pressure value outside the given range in a given number of consecutive checks substantially indicates a shift in the setting of sensor 18 in that, the congruency test being slower than the others, other types of fault are generally detected earlier.

In the event of a negative finding in any one of the four tests (as shown in Figure 3 by OR port 35), a fault signal is generated and the engine stopped (block 36).

The method described thus provides, in a straightforward, reliable manner, for indicating otherwise undetectable faults in the hydraulic circuit - such as locking of an injector in the open position - by

detecting extraneous factors unrelated to faults resulting in a transient variation in circuit control quantities.

Clearly, changes may be made to the method as described and illustrated herein without, however, departing from the scope of the present invention.

CLAIMS

1) A method of diagnosing malfunctioning of the high-pressure circuit of internal combustion engine high-pressure injection systems; said circuit including a high-pressure pump (6) for supplying fuel at a pressure value controlled by means of control cycles; characterized in that it comprises the steps of monitoring quantities correlated to the pressure generated by said high-pressure pump (6) in successive control cycles; comparing the pattern of said quantities in said successive control cycles with reference values; and generating fault signals in the event said pattern fails to present a predetermined relationship with said reference values.

2) A method as claimed in Claim 1, characterized in that it provides for measuring the pressure supplied by said high-pressure pump (6) to a manifold (10); comparing said measured pressure with a maximum reference value; and generating a fault signal in the event said measured pressure exceeds said maximum value in a predetermined number of consecutive control cycles.

3) A method as claimed in Claim 1 or 2, characterized in that it provides for measuring the pressure supplied by said high-pressure pump (6) to a manifold (10); comparing said measured pressure with a minimum reference value; and generating a fault signal in the event said measured pressure is below said

minimum value in a predetermined number of consecutive cycles.

4) A method as claimed in Claim 3, characterized in that said minimum reference value varies as a function of the speed of the engine (16).

5) A method as claimed in any one of the foregoing Claims, wherein said control cycles comprise the step of varying the duty cycle of the current supply to the pressure regulating solenoid valve (7) of said high-pressure pump (6); characterized in that it provides for measuring the pressure supplied by said high-pressure pump; calculating the duty cycle of the current supply on the basis of the error between a required pressure value and said measured pressure; comparing said calculated duty cycle with a minimum and maximum reference value; and generating a fault signal in the event said calculated duty cycle fails, in a predetermined number of consecutive control cycles, to fall within the acceptance range defined by said minimum and maximum values.

6) A method as claimed in any one of the foregoing Claims, wherein said control cycles comprise the step of varying the duty cycle of the current supply to the pressure regulating solenoid valve (7) of said high-pressure pump (6); characterized in that it provides for measuring the pressure supplied by said high-pressure pump; calculating the duty cycle of the current supply on the basis of the error between a

required pressure value and said measured pressure; determining a reference pressure value on the basis of said calculated duty cycle; comparing said measured pressure and said reference pressure value; and generating a fault signal in the event said measured pressure fails, in a predetermined number of consecutive control cycles, to match said reference pressure value within a predetermined tolerance.

7) A method as claimed in Claim 6, characterized in that said step of determining a reference pressure value comprises reading said reference pressure value in a map in which pressure values as a function of duty cycle are memorized.

8) A method of diagnosing malfunctioning of the high-pressure circuit of internal combustion engine high-pressure injection systems, substantially as described and illustrated herein with reference to the accompanying drawings.

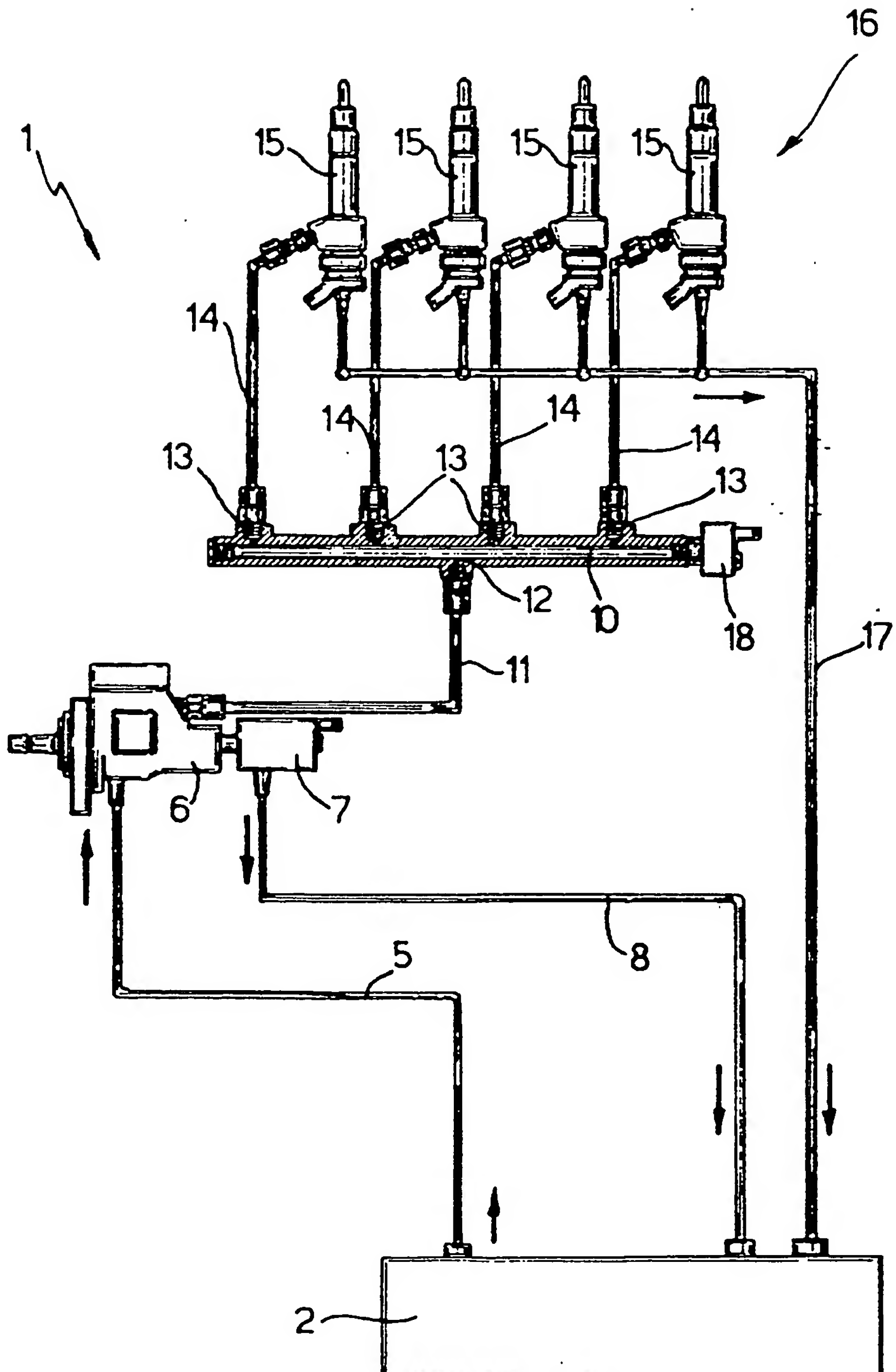


Fig.1

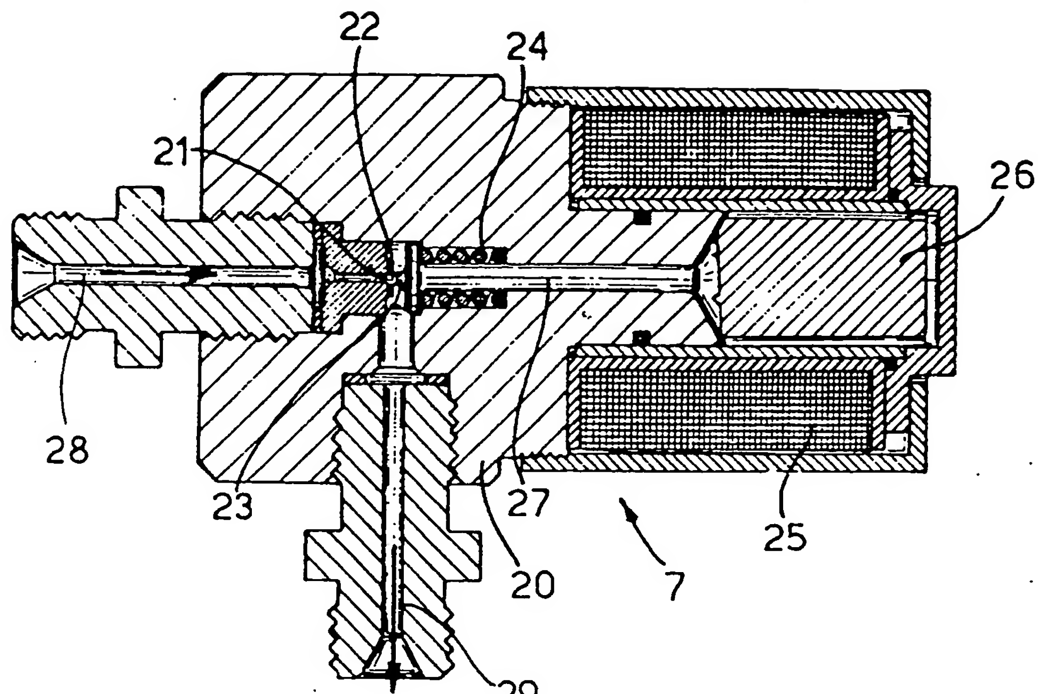

22
24
21
26
28
23
27
25
20
7
29

Fig. 2

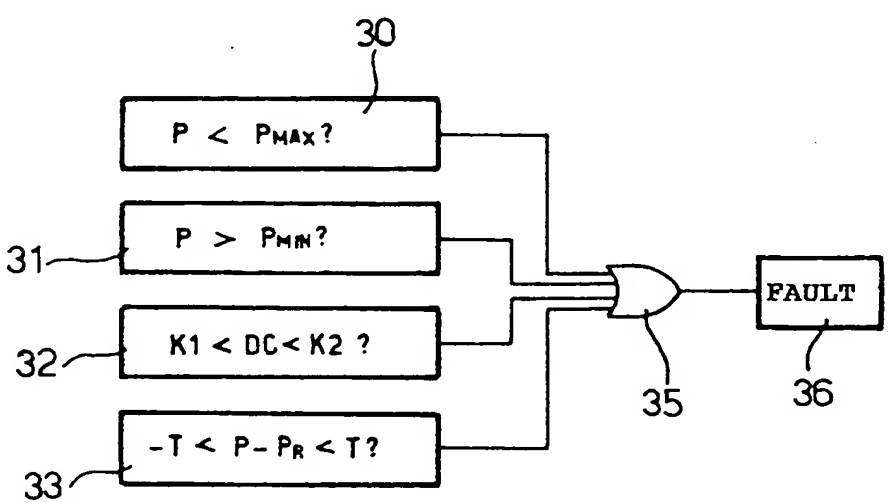
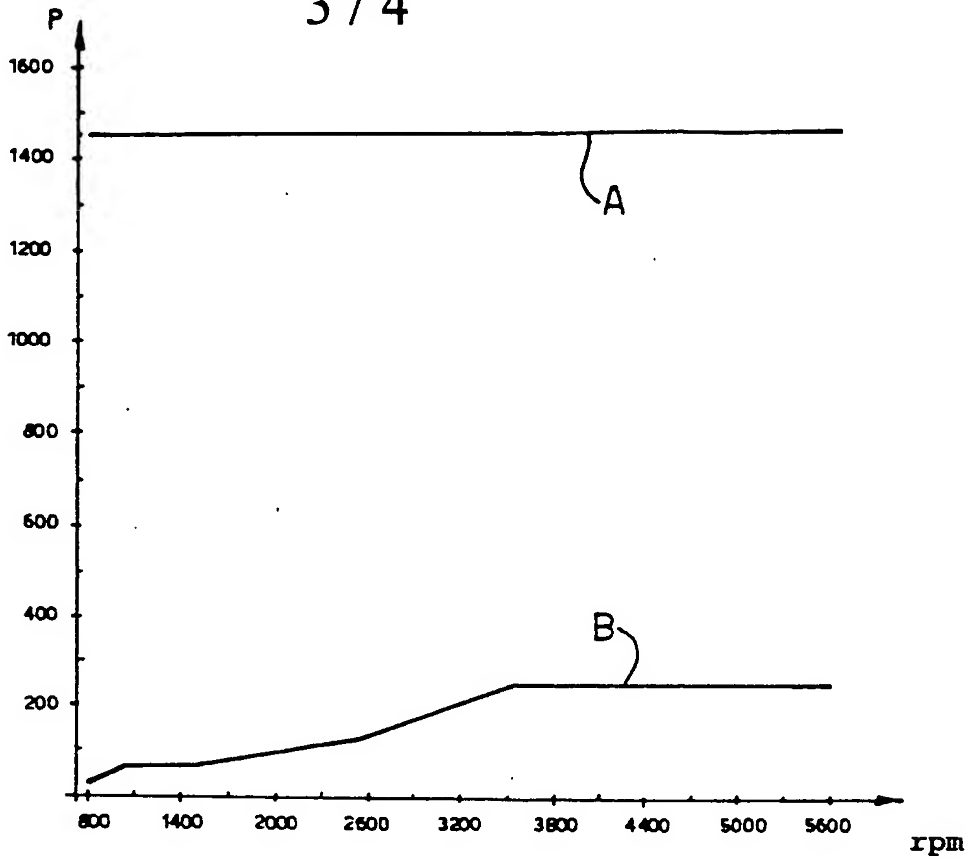

30
P < PMAX?
31
P > PMIN?
32
K1 < DC < K2 ?
33
-T < P - PR < T?
FAULT
35
36

Fig. 3


P
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1400
1200
1000
800
600
400
200
A
B
800
1400
2000
2600
3200
3800
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5000
5600
rpm

Fig 4

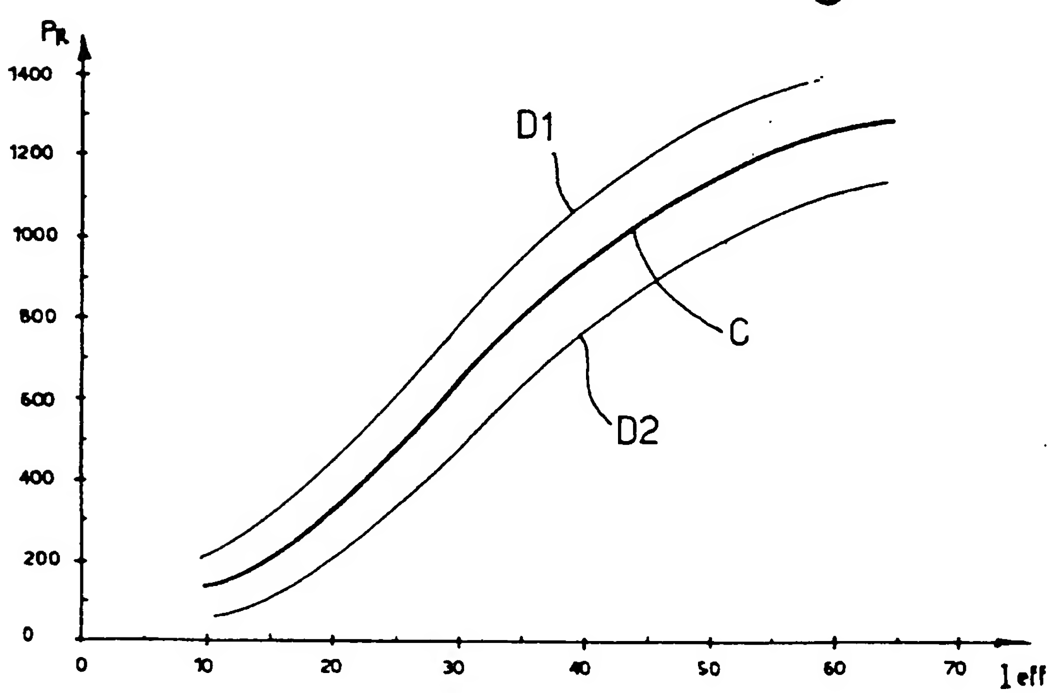
P_R
1400
1200
1000
800
600
400
200
0
D1
C
D2
0
10
20
30
40
50
60
70
I_{eff}

Fig. 6

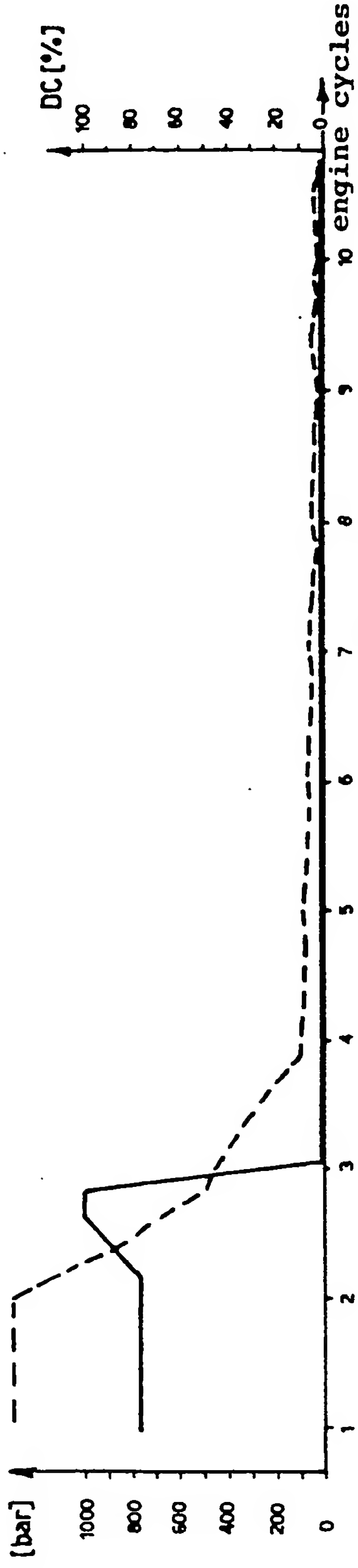

Fig.5 A

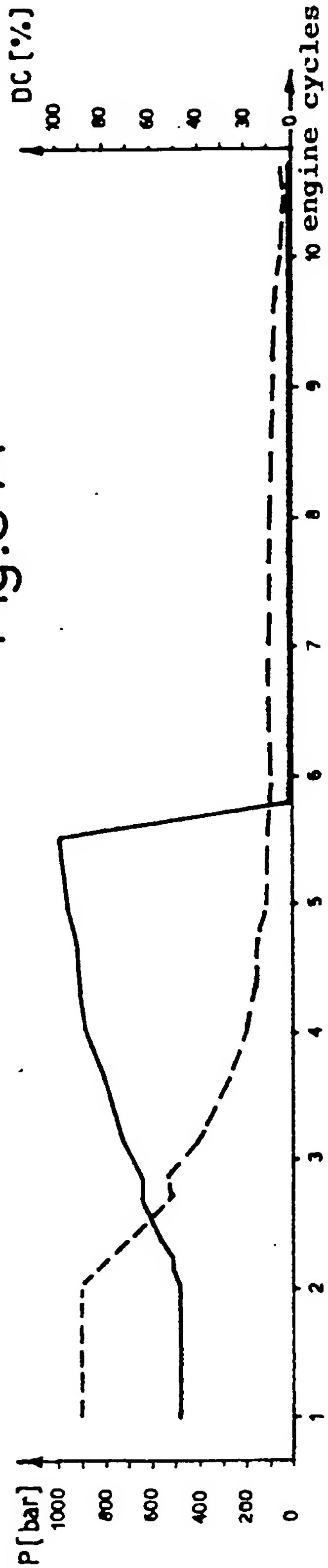

Fig.5 B

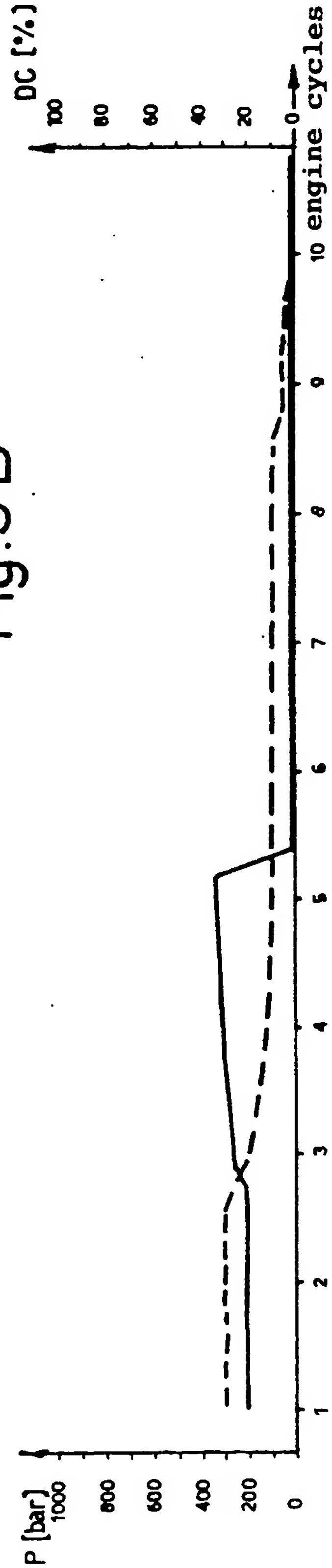

Fig.5 C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP 94/02922

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 F02D41/38 F02D41/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 F02D F02M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 501 459 (NIPPONDENSO CO.,LTD.) 2 September 1992 see column 9, line 30 - column 15, line 4; figure 10 ---	1,3,4
P,A	US,A,5 241 933 (MORIKAWA) 7 September 1993 see column 1, line 54 - column 2, line 48 see column 4, line 47 - column 5, line 36 ---	1-3,5,6, 8
A	FR,A,2 672 640 (ROBERT BOSCH GMBH) 14 August 1992 see page 1, line 4 - line 24 see page 2, line 17 - page 3, line 34; figures ---	1
A	GB,A,2 133 906 (ROBERT BOSCH GMBH) 1 August 1984 -----	

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☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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